LSST Observing Strategy and Supernovae

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2 Laboratoire de Physique des Hautes Energies IN2P3/CNRS
Supernovae and Dark Energy

Distance modulus vs. Redshift graph with data points and labels for Hubble diagram, SNLS, SDSS, Low-z, and HST.
Supernovae and Dark Energy

Hubble diagram

\[ \mu = m^*_B - M(G) + aX_1 - \beta C \]

\( \sim 740 \) Supernovae

Distance modulus

Redshift

Cosmology (fit)

-> Dark Energy constraints
Supernovae and Dark Energy

**Hubble diagram**

$\mu = m_B^* - M(G) + \alpha x_1 - \beta C$

~ 740 Supernovae

**LSST**: type Ia Supernovae for Hubble diagram

- large sample (x few 100)
- well calibrated (photometry) well measured
- with minimal bias (ie high redshift completeness)

Cosmology (fit) -&gt; Dark Energy constraints
Supernovae and Dark Energy

Hubble diagram

Distance modulus

Redshift

Space Obs. (EUCLID, WFIRST)

LSST compl.
Supernovae and Dark Energy

Distance modulus

\[ \mu = m_B - M(G) + aX_1 - \beta C \]

Hubble diagram

LSST

WFD

DDF

SNLS


Space Obs. (EUCLID, WFIRST)

LSST compl.
Supernovae and Dark Energy

Distance modulus

\[ \mu = m_B^* - M(G) + \alpha X_1 - \beta C \]

\[ \mu \leftarrow \text{error on distance modulus dominated by } \sigma_C \]

\[ \sigma_C \leq 0.04 \ (\sigma_\mu \leq 0.1) \]

Extracted from light curves

Quality -> Observing Strategy

Hubble diagram

LSST

WFD

SNLS

### Main parameters driving SN science

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Impact</th>
<th>Typical value</th>
</tr>
</thead>
<tbody>
<tr>
<td>cadence + multiband</td>
<td>Light curve quality (SN parameters estimation)</td>
<td>median: 3 days⁻¹ with limited variations</td>
</tr>
<tr>
<td>observations</td>
<td></td>
<td></td>
</tr>
<tr>
<td>season length</td>
<td>Number of SN collected</td>
<td>170-180 days</td>
</tr>
<tr>
<td>depth</td>
<td>High z detection</td>
<td>5-σ depth ~ 26.5, 26.2, 25.6, 24.7 for r, i, z, y bands (DDF)</td>
</tr>
</tbody>
</table>

The goal: collect a large and unbiased \((z \leq 0.8 \text{ DDF})\) sample of well measured \((\sigma_c \leq 0.04)\) type Ia supernovae.
**LSST Observing Strategy**

Total number of visits: ~ 2,450,000  
(1 visit = 30s exposure time)

3 types of surveys:
- universal (WFD) ~ 90% -> Supernovae
- mini-surveys: ~5%  
- Deep (DDF): ~5% -> Supernovae

<table>
<thead>
<tr>
<th>Survey</th>
<th>Science</th>
</tr>
</thead>
<tbody>
<tr>
<td>WFD</td>
<td>Parallaxes, proper motions, asteroids, transients,...</td>
</tr>
<tr>
<td>mini-surveys</td>
<td>Magellanic clouds, asteroids (NEA, MB)</td>
</tr>
<tr>
<td>DDF</td>
<td>Transients (Supernovae)</td>
</tr>
</tbody>
</table>

Supernovae: strong constraints on cadence, depth, season length, area.

-> 90 to 95% of the survey (WFD+DDF)
LSST Observing Strategy

LSST observing strategy is not defined yet.

Open questions:
- Fraction of each type of survey?
- Area?
- Depths (per band)?
- Cadence (per band)?
- Filter allocation (per night or globally)?
- How should the sky be observed?
- Exposure times?
- Season lengths?
- ...

We have quite a lot of simulations with these parameters varying. We use sets of metrics to estimate which observing strategy are optimal for SN science.
LSST Observing Strategy - Methods to scan the sky

At the end of a night

OpSim: greedy algorithm optimizing observing conditions and minimizing slew time

alt_sched: systematic scans at the meridian; dense parts of the sky per night; lots of filter swaps.

FBS: markov chain decision process (slew time, image depth and desired footprint)
LSST Observing Strategy - Methods to scan the sky

**Filter Allocation**

<table>
<thead>
<tr>
<th></th>
<th>OpSim</th>
<th>FBS</th>
<th>alt_sched</th>
</tr>
</thead>
<tbody>
<tr>
<td>u</td>
<td>7%</td>
<td>7%</td>
<td>8%</td>
</tr>
<tr>
<td>g</td>
<td>10%</td>
<td>10%</td>
<td>10%</td>
</tr>
<tr>
<td>r</td>
<td>21%</td>
<td>22%</td>
<td>28%</td>
</tr>
<tr>
<td>i</td>
<td>22%</td>
<td>22%</td>
<td>18%</td>
</tr>
<tr>
<td>z</td>
<td>20%</td>
<td>20%</td>
<td>26%</td>
</tr>
<tr>
<td>y</td>
<td>18%</td>
<td>18%</td>
<td>9%</td>
</tr>
</tbody>
</table>

**Number of Filter Changes per Night**

- **OpSim**
  - Green line: baseline_1exp_nopairs_10yrs
  - Orange line: kraken_2026
  - Blue line: alt_sched

- **FBS**
  - Blue line: alt_sched

**Histogram**

- X-axis: Number of Entries
- Y-axis: Number of Filter Changes per Night
LSST Observing Strategy - Methods to scan the sky

Filter allocation

<table>
<thead>
<tr>
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Median cadence after 10 years

<table>
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<tr>
<th></th>
<th>g</th>
<th>r</th>
<th>i</th>
</tr>
</thead>
<tbody>
<tr>
<td>alt_scheduled</td>
<td>10.5</td>
<td>4.0</td>
<td>6.0</td>
</tr>
<tr>
<td>FBS</td>
<td>17.9</td>
<td>9.0</td>
<td>10.5</td>
</tr>
</tbody>
</table>
A set of metrics to assess impact of observing strategies:
- Number of well-sampled supernovae ($N_{SN, z_{limit}}$)
- Cadence metric
- Rate of SN with $SNR_{SNR_{median}}$
- Figure of Merit ($w_0, w_a$)
- Photometric classification
- Peculiar velocity
- ...

Most of these metrics do not rely on full simulations (time consumption) but on proxies as precise as possible (trade-off precision/processing time).

Some of these metrics are estimated using two types of supernovae:
- “Faint”: $(x1, color) = (-2.0, 0.2)$
- “Medium”: $(x1, color) = (0.0, 0.0)$
LSST Observing Strategy and SN – Cadence metric

**Cadence metric**

\[ f_\theta < \delta_i > ^{-1/2} \leq \frac{5 \sqrt{\Delta t} \sqrt{\sum I_i^2}}{\text{SNR}} \]

- Observing strategy
- Average 5-σ depth
- Limit in e/s/day
- Supernovae science

![Graph showing cadence and 5-σ depth with zlim values of 0.3, 0.4, 0.5, and 0.6 in the r band.]
snaps (2 exposures of 15 s) vs “no snaps” (1 exposure of 30s)
-> would allow a gain of observing time (+7%)
-> But one exposure of 30s increases saturation effects (also depends on the ccd full well)

<table>
<thead>
<tr>
<th>Exptime (s)</th>
<th>ccd full well(kpe)</th>
<th>$\Delta m_{\text{sat}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>120</td>
<td>-0.31</td>
</tr>
<tr>
<td>30</td>
<td>90</td>
<td>+0.75</td>
</tr>
<tr>
<td>30</td>
<td>120</td>
<td>+0.44</td>
</tr>
</tbody>
</table>

wrt current baseline
exptime=15s, fw = 90 kpe
Saturation occurs after 5 to 7 days
-> tight wrt cadence: early identification?

At least 3 LC points
± 4 days around max lumi

no snaps
snaps
no snaps

Selection efficiency
LSST Observing Strategy and SN – DDF

4 fields already selected

<table>
<thead>
<tr>
<th>Field</th>
<th>(RA,Dec) (deg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ELAIS-S1</td>
<td>(0.00, -45.52)</td>
</tr>
<tr>
<td>CDFS</td>
<td>(53.01, -27.44)</td>
</tr>
<tr>
<td>XMM-LSS</td>
<td>(34.39, -5.09)</td>
</tr>
<tr>
<td>COSMOS</td>
<td>(150.36, 2.84)</td>
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A 5th field overlap with EUCLID and WFIRST

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</tr>
<tr>
<td>COSMOS</td>
<td>(150.36, 2.84)</td>
</tr>
<tr>
<td>Akari South DF</td>
<td>(71.0, -53.3)</td>
</tr>
</tbody>
</table>
- Observing strategy (in terms of cadence and depth) is not finalized yet.
- Constraint: DDF program: 6-7% (upper limit) of LSST survey
- Simulations with at least 4 fields (SPT for the 5th) - cadences of about few days/exposure times for g/r/i/z/y of 300/600/600/780/600 sec.
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**Very good scenario (4 DDF)**
- Regular cadence (3 days)
- No large gaps
- Long seasons (180 days)
A new observing strategy has been proposed in arXiv:1812.00516

- High cadence with intertwined band observations
- COSMOS: every night with night1: gri and night2: zy
- ELAIS, CDFS, XMM: every 3 nights with: night1: gri, night2: zy, night3: nothing
- depth: grizy: 2/4/8/25/4 visits
- This would correspond to about 5.7% of the total observing time.

Simulations of this scenario are being analyzed.
This scenario may be tuned depending on how the DDF survey will be planed (sharing with AGN)
LSST Observing Strategy and SN – Summary

- Lots of observing strategies simulated and assessed using SN metrics
  - **WFD**
    -> recent simulations show clear improvements
    -> close to a set of scenarios leading to a *large* sample of *well-measured* type Ia supernovae
  - **DDF**
    -> limited to 6-7% of LSST survey -> 5 DDF at max
    -> scenarios to be tuned (cadence, depth, compl. EUCLID/WFIRST, sharing with AGN)
  - **Saturation**
    -> low-z SN (effects up to $z \lesssim 0.030-0.035$)
    -> better to have 2x15s exposures (effects up to $z \lesssim 0.020-0.025$)
  - **Early identification/spectroscopic follow-up**
    -> early identification of SN has to be studied to define the spectroscopic follow-up program
<table>
<thead>
<tr>
<th>Event</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Call for white papers</td>
<td>June 30, 2018</td>
</tr>
<tr>
<td>White paper submitted</td>
<td>Nov 30, 2018</td>
</tr>
<tr>
<td>List of to-be-simulated survey strategies</td>
<td>April 2019</td>
</tr>
<tr>
<td>Simulated survey strategies available</td>
<td>End of 2019</td>
</tr>
<tr>
<td>Survey Strategy Committee (SSC)</td>
<td>Early 2020</td>
</tr>
<tr>
<td>SSC report on official initial LSST survey strategy</td>
<td>Early 2021</td>
</tr>
<tr>
<td>Baseline simulation of initial LSST survey strategy</td>
<td>Mid 2021</td>
</tr>
<tr>
<td>Start of LSST operations</td>
<td>2022</td>
</tr>
<tr>
<td>Regular survey reviews by the SSC</td>
<td>2022-2032</td>
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